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DEVELOPMENT OF A VIRTUAL REALITY SYSTEM TO PROMOTE INDIGENOUS CULTURAL HERITAGE AND ENVIRONMENTAL EDUCATION

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Abstract. *This study examined how a VR360 learning system integrating Tao Indigenous culture and the ecological environment of Orchid Island, Taiwan, influences students' learning achievement, learning motivation, cognitive load, and technology acceptance. The study aimed to determine whether such culturally grounded VR learning experiences can support educational equity and foster deeper cultural understanding. A quasi-experimental pretest–posttest design was employed to compare Indigenous and non-Indigenous elementary students who both received the VR intervention. Data were collected using validated instruments, including a learning achievement test, a motivation scale, a cognitive load scale, and a technology acceptance questionnaire. The participants comprised 64 students from grades three to six in northern Taiwan (33 Indigenous and 31 non-Indigenous). Both groups demonstrated significant gains in learning achievement following the intervention, with the non-Indigenous group achieving higher scores. Indigenous students reported higher, though not statistically significant, motivation to learn about the Tao cultural heritage and experienced slightly higher cognitive load during the learning process. Both groups expressed high acceptance of the VR360 system. These findings highlight the potential of VR as an effective and culturally responsive educational tool that supports immersive learning and promotes educational equity, offering valuable insights for the design of localized and multicultural learning experiences.*

Keywords: *digital divide, ecological preservation, Indigenous cultural heritage, sustainable development, virtual reality*

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Introduction

The Tao Tribe (also known as the Yami) is one of Taiwan's Indigenous peoples and the only group whose primary residence is on an offshore island—Orchid Island, located off Taiwan's southeastern coast. Shaped by a maritime environment, the Tao people have developed a culture rooted in harmony with nature and extensive ecological knowledge of marine ecosystems. Fishing lies at the heart of their livelihood, with flying fish holding profound spiritual and cultural significance. The annual Flying Fish Festival marks the fishing season and reflects ancestral customs that emphasize sustainability. Beyond the Flying Fish Festival, the Tao people's defining traditions, including plank boat craftsmanship, semi-subterranean dwellings, and seafaring practices, represent vital elements of Taiwan's intangible cultural heritage.

Research Problem

Orchid Island hosts a rich and diverse ecosystem, featuring unique marine species and vibrant coral reefs. However, climate change, tourism development, and environmental pollution increasingly threaten this fragile environment. Protecting the ecosystem is therefore critical, not only for the Tao people but also for safeguarding Taiwan's biodiversity. Environmental education plays a key role in fostering ecological awareness and promoting sustainable behaviors. Indigenous communities possess deep, holistic knowledge of their local environments, landscapes, and ecosystems, contributing significantly to biodiversity conservation and sustainable development. Respecting Indigenous cultures, protecting local environments, and valuing native perspectives on environmental stewardship are thus essential for advancing environmental education. In this context, enhancing ecological conservation has become a vital strategy for preserving both the traditional culture of Taiwan's Indigenous peoples and the long-term sustainability of

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natural environments. Yet, current approaches to environmental education often fail to engage elementary and high school learners or to effectively convey the immersive cultural and ecological knowledge of Indigenous communities, underscoring the need for innovative tools. Therefore, this study used virtual reality (VR) as a learning tool to connect cultural heritage with environmental awareness.

Research Focus

Indigenous students often face challenges in using digital learning materials, including limited access to ICT devices, unstable internet connectivity, and unequal distribution of technology-related educational resources. Many Indigenous schools also struggle with outdated or inadequate digital infrastructure, putting students at a disadvantage in developing new technological skills. To address these issues, this study leveraged the cultural context of the Tao people and the ecological environment of Orchid Island to develop a simple, user-friendly learning tool using smartphones combined with low-cost, portable Cardboard VR headsets. Through interactive feedback mechanisms, students can engage in self-paced learning to enhance both interest and motivation (Chittaro & Buttussi, 2015).

Multicultural science education is a reform initiative aimed at ensuring equitable opportunities for learners from diverse cultural, linguistic, and socioeconomic backgrounds to engage in science learning in both formal and informal settings. It challenges traditional, one-size-fits-all approaches by recognizing that students' cultural identities influence how they interpret and relate to scientific knowledge. Current trends emphasize "inclusive science for all" strategies to support culturally responsive teaching and integrate students' experiences into the curriculum. Therefore, governments and educators are encouraged to make science education accessible and culturally relevant, helping students appreciate the contributions of diverse cultures, ethnicities, and genders. Such efforts foster scientific literacy, cultural understanding, and social equity (Aikenhead & Michell, 2011).

Although previous studies have shown that VR can enhance learners' engagement, motivation, and conceptual understanding in environmental education, few have explored its application within Indigenous cultural contexts. Prior research on the use of VR in education has primarily focused on scientific concepts or environmental simulations, without incorporating Indigenous worldviews, traditional knowledge systems, or place-based perspectives. Moreover, studies in Indigenous education have often emphasized cultural preservation or language revitalization through storytelling, rather than integrating immersive technologies into formal school curricula.

Another limitation of prior work is the reliance on high-cost or laboratory-based VR systems, which limits accessibility and practicality in remote or under-resourced Indigenous communities. Consequently, there remains a lack of empirical evidence on how culturally responsive, affordable VR tools can simultaneously promote understanding of cultural heritage, environmental awareness, and digital inclusion among elementary students (Hilbert, 2011). To address these gaps, the present study developed and evaluated a low-cost VR360 learning system that integrates Tao Indigenous cultural heritage with the ecological environment of Orchid Island. This approach not only advances the application of VR in Indigenous education but also contributes to reducing the digital divide in remote areas and promoting equity in technology-enhanced learning.

Related Work and Theoretical Background

In response to the diversification of instructional methodologies, it is essential to integrate digital technologies within innovative pedagogical frameworks to ensure their meaningful and equitable contribution to learning. With the growing adoption of mobile technologies in educational settings and the ongoing expansion of network infrastructure in remote regions, the development of digital learning materials through advanced educational technologies can enhance Indigenous students' digital literacy, stimulate their interest and motivation, and foster self-directed learning skills. The proposed VR360 system offers an effective means of promoting Indigenous cultural knowledge and ecological awareness, making it an effective tool for implementing environmental education in Indigenous school contexts. The following sections provide a review of relevant literature to situate this study within established theoretical and empirical frameworks.

Virtual Reality

With the rise of the metaverse, VR technology has become increasingly integrated into education (Radianti et al., 2020; Hamilton et al., 2021). As an innovative approach, VR immerses learners in realistic digital environments that support situated learning and authentic knowledge application (Araiza-Alba et al., 2021; Huey & Ferguson,

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2022; Hu-Au & Lee, 2018). Empirical studies have shown that VR can enhance comprehension, motivation, and cognitive development (Tsichouridis et al., 2020). However, findings remain mixed: some studies have reported increased motivation and understanding (Parong & Mayer, 2018), while others have cautioned that excessive visual complexity can overload learners' cognition and reduce instructional effectiveness (Makransky & Petersen, 2021; McLean et al., 2020). These inconsistencies suggest that the effectiveness of VR depends on design quality, learner characteristics, and educational context.

In elementary education, integrating VR with experiential tasks has been shown to improve conceptual understanding and engagement (Chang et al., 2020). Yet, high VR equipment costs and connectivity requirements limit its use in under-resourced or rural schools (Martín-Gutiérrez et al., 2017). Recently, the emergence of VR360, which uses 360-degree panoramic images viewed through mobile devices, offers a practical alternative, providing immersive experiences through low-cost devices such as Google Cardboard and enabling exploration of authentic panoramic environments (Rosendahl & Wagner, 2024; Lee et al., 2021). Although VR360 can enhance ecological awareness and motivation, its limited interactivity may reduce learning depth compared with fully interactive VR systems (Boda & Brown, 2020).

VR has shown its potential in environmental and cultural education by fostering empathy and a sense of responsibility toward nature (Xie & Yang, 2024) and enabling vivid visualization of climate change impacts (Markowitz & Bailenson, 2021; Newton et al., 2024). However, few studies have adapted such immersive experiences to Indigenous contexts, where learning emphasizes place-based knowledge and storytelling. While VR can challenge stereotypes and promote cultural understanding (Shadiev et al., 2024), existing research has primarily targeted adult or museum audiences rather than school-aged learners. To address these gaps, the present study developed a culturally grounded VR360 system integrating Tao Indigenous heritage with the ecology of Orchid Island. By examining learning achievement, motivation, cognitive load, and technology acceptance among Indigenous and non-Indigenous students, this research evaluates how accessible VR experiences can support cultural preservation, environmental awareness, and educational equity.

This study adopts a VR-based learning model in which immersion, cognitive load, and learning motivation act as mediators linking VR experiences to learning outcomes. In immersive environments, sensory realism and interactivity enhance presence, stimulating intrinsic motivation and engagement (Makransky & Petersen, 2021; Parong & Mayer, 2018; Portuguez-Castro & Santos Garduño, 2024). However, excessive realism or overly complex interfaces can increase extraneous cognitive load and hinder comprehension (Sweller, 2011). Effective VR instructional design balances immersion with cognitive demands, sustaining motivation and facilitating meaningful learning. Specifically, higher immersion may reduce extraneous load by providing intuitive, context-rich learning while enhancing intrinsic motivation through engagement and relevance. These factors, in turn, may predict learning outcomes such as achievement and technology acceptance. The model can be visually represented with directional pathways illustrating how VR immersion influences cognitive and motivational processes, ultimately leading to improved learning performance. Therefore, well-designed immersive experiences can enhance learning motivation, reduce extraneous cognitive load, and improve learning achievement and technology acceptance in VR-based education.

Tao Culture and Traditional Rituals

The Tao people's livelihood is closely intertwined with the maritime environment, where fishing forms the core of both their economy and cultural identity. Their clan-based society is organized into fishing and agricultural collectives, with men primarily engaged in fishing and women cultivating staple crops such as millet, taro, and sweet potatoes. The Tatala, a traditional plank canoe, embodies both subsistence and spiritual significance, with its construction reflecting ecological wisdom and deep respect for natural resources. Flying fish, regarded as sacred gifts, are caught under strict cultural taboos to maintain ecological balance. The annual Flying Fish Festival (March–June), including the Fish-Summoning, Storing, and Final Fish rituals, reinforces communal values of sustainability and reverence for nature. Distinctive semi-subterranean houses, where the number of doors signifies social status, further showcase Tao craftsmanship and social organization.

Rituals such as house completion and boat-launching ceremonies, accompanied by songs and offerings, serve as expressions of gratitude and respect toward both the sea and the community. Traditional songs act as oral archives, transmitting ecological knowledge, history, and moral values across generations. However, modernization and external cultural influences increasingly threaten this heritage, limiting understanding among younger generations and non-Indigenous populations. Integrating digital technologies for the preservation and transmission of Tao cultural heritage is therefore essential for sustaining its continuity within contemporary education.

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In response, this study employed VR to develop an immersive learning system centered on Tao Indigenous culture and Orchid Island's natural environment. By incorporating key cultural events, such as the Flying Fish Festival and the Tatala Launching Ceremony, the VR360 system enables learners to virtually experience the Tao people's profound relationship with their cultural heritage and ecological surroundings. This approach fosters deeper understanding, respect, and cultural identity, highlighting Indigenous knowledge and diversity while offering innovative and practical strategies for advancing Indigenous cultural and environmental education.

Indigenous Science Learning

Indigenous science refers to knowledge systems developed over generations through continuous interaction between Indigenous peoples and their environments. It encompasses ecological, climatic, and environmental understanding transmitted through oral traditions and lived practices (Snively & Corsiglia, 2001). Whereas Western science emphasizes analytical reasoning and universal laws, Indigenous science prioritizes relational, place-based knowledge rooted in harmony with nature (Ogawa, 1995). This epistemological divergence makes integration into formal curricula challenging, as Indigenous science resists reduction to standardized frameworks (Aikenhead & Ogawa, 2007).

Empirical studies have explored ways to bridge these paradigms, though findings remain mixed. Cobern (1996) suggested that contextualizing scientific content within cultural frameworks enhances motivation and comprehension, particularly for Indigenous learners. Conversely, others caution that superficial cultural references—absent genuine community participation—can lead to tokenism rather than meaningful learning. While the educational value of Indigenous science is widely recognized, its authentic application remains uneven. Lee et al. (2012) demonstrated a culturally responsive approach with Amis fourth graders in Taiwan, integrating Indigenous cyclical time concepts with Western linear time. The results showed improved coherence in students' scientific understanding and strengthened cultural identity. However, the localized scope and short-term implementation limit generalizability, and potential cognitive tensions between Indigenous and Western epistemologies remain unexplored. Recent work reinforced the motivational benefits of integrating Indigenous knowledge but maintained a predominantly Western pedagogical framework (Ogegbo & Ramnarain, 2024), highlighting a persistent tension in which Indigenous science is treated as supplementary rather than equal.

Collectively, prior studies have underscored the potential of cultural integration to enhance engagement and identity while revealing unresolved challenges of authenticity, scalability, and epistemic balance. To address these gaps, this study employs VR360 technology to recreate Tao ecological knowledge and cultural practices, including the Flying Fish Festival and traditional semi- subterranean houses. By immersing learners in Indigenous and ecological perspectives, this approach contextualizes abstract scientific concepts and examines how digital tools can convey Indigenous science with cultural integrity. In doing so, it addresses existing contradictions and advances the development of inclusive, culturally grounded science education.

Learning Motivation

Learning motivation refers to the internal drive or external incentives that stimulate a learner's desire to engage in and persist with educational activities. It plays a critical role in influencing students' attention, effort, and overall academic success. Motivated learners are more likely to set goals, adopt effective learning strategies, and overcome challenges. Motivation can be categorized as intrinsic, arising from curiosity and personal interest, and extrinsic, driven by rewards or recognition. Within educational contexts, fostering motivation is essential, as it directly affects engagement, knowledge retention, and performance. Enhancing learners' motivation is therefore a key focus in developing effective teaching strategies and supportive learning environments (Schunk et al., 2014).

VR applications have been shown to effectively increase students' concentration and foster intrinsic motivation. The immersive and interactive experiences of VR make learning more engaging and impactful, particularly in contexts requiring sustained attention. Research indicates that, compared to self-centered narratives (e.g., treasure hunts), VR activities with other-centered narratives (e.g., rescuing others) more effectively enhance intrinsic motivation. This effect may stem from the fact that prosocial behavior satisfies individuals' need for belonging, thereby strengthening their desire to learn (Jahn et al., 2025). Additionally, VR creates immersive learning environments, especially beneficial for developing skills such as language acquisition (Li, 2023). Compared with lecture-based teaching methods, VR instruction demonstrates greater advantages in fostering students' interest, enjoyment, and sense of autonomy in learning (Lin et al., 2017).

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Learning motivation is a critical determinant of academic outcomes, and immersive technologies offer significant potential to enhance it. For Indigenous students, culturally relevant and immersive content can effectively stimulate intrinsic motivation while reinforcing cultural identity. Accordingly, this study has employed VR360 technology to develop an immersive learning system integrating Tao cultural heritage with Indigenous scientific knowledge. The VR360 system aims to enhance learners' motivation and engagement through culturally connected, interactive instruction. This design not only aligns with current trends in technology-assisted learning but also addresses the lack of interactive, context-rich educational materials in Indigenous culture and environmental education. Moreover, it explores the impact of VR360 on learning motivation, providing both practical and theoretical insights into the integration of Indigenous culture, technology, and science education.

Cognitive Load

Cognitive Load Theory (CLT) explains the amount of mental effort invested during learning, which is influenced by the way instructional content is presented and its intrinsic complexity (Kalyuga, 2011; Zu et al., 2020). CLT distinguishes three types of cognitive load:

- **Intrinsic Cognitive Load:** Stems from the inherent complexity of the learning material; more complex content demands greater cognitive effort to understand.
- **Extraneous Cognitive Load:** Results from ineffective instructional design, such as disorganized content or unnecessary visuals, which distract learners and hinder comprehension.
- **Germane Cognitive Load:** Involves the cognitive effort devoted to integrating new information with prior knowledge, supporting meaningful learning and schema development.

Compared with traditional science instruction, VR learning environments can manage intrinsic and reduce extraneous cognitive load while directing germane load toward deeper learning. By simplifying complex concepts and promoting active information processing, immersive experiences, especially in hands-on or procedural contexts—provide realistic engagement that lowers learners' cognitive burden (Wang et al., 2025). Evidence from existing research supports VR's ability to regulate cognitive load, offering a strong theoretical foundation for using immersive strategies to enhance learning efficiency and comprehension. In the present study, VR360 technology was integrated with Tao cultural and scientific content to create an immersive learning experience designed to optimize cognitive load associated with understanding culturally rich and conceptually complex materials. The VR360 system fosters meaningful learning and strengthens knowledge internalization with optimized instructional design and interactive immersion.

Technology Acceptance Model

The Technology Acceptance Model (TAM) is widely used to evaluate users' acceptance of and intention to adopt information technologies. This model is grounded in three key factors: Perceived Usefulness (PU), Perceived Ease of Use (PEOU), and Intention to Use (ITU), which together reflect users' attitudes toward embracing new technological tools (Scherer et al., 2019; Marikyan & Papagiannidis, 2024).

- **Perceived Usefulness (PU):** The extent to which an individual believes that a specific technology will enhance task performance. In educational contexts, this refers to students' perceptions of technologies (such as VR) as tools that improve understanding and learning outcomes.
- **Perceived Ease of Use (PEOU):** The extent to which users feel that a technology is intuitive and requires minimal effort to operate. This includes ease of navigation, clarity of controls, and overall user-friendliness, all of which strongly influence the likelihood of adoption.
- **Intention to Use (ITU):** The willingness or likelihood to adopt and continue using a particular technology. ITU reflects behavioral commitment shaped by perceived usefulness, ease of use, and satisfaction, serving as a strong predictor of actual usage.

Within TAM, users' attitudes toward a technology are shaped by PU and PEOU, which in turn influence their ITU. A favorable perception of usefulness and accessibility increases the likelihood of adoption, making ITU a critical mediating variable between the core constructs and actual technology use. As such, ITU is considered a key indicator of technological success (Zhou et al., 2022). TAM has been extended and applied across multiple domains, including healthcare, e-commerce, and business analytics (Alsyouf et al., 2023; Mbazu et al., 2024; Nadlifatin et al., 2024).

In this study, the TAM framework was employed to examine students' acceptance of the VR360 system in learning contexts, focusing on how perceived usefulness and ease of use influence attitudes and intention to use

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the VR technology for cultural and environmental education. Because the VR360 system aims to enhance students' understanding and engagement with its learning content, TAM provides a theoretical foundation for assessing how this technological intervention shapes learning attitudes and behaviors. Furthermore, TAM offers valuable insights into factors affecting Indigenous students' acceptance of innovative educational technologies, informing strategies to support the future integration of VR360 into culturally responsive instructional design.

Research Aim and Research Questions

The aim of this study was to develop and evaluate a VR360 system that integrates Tao Indigenous culture with the ecological environment of Orchid Island, and to examine its effects on Indigenous and non-Indigenous elementary students' learning achievement, learning motivation, cognitive load, and the technology acceptance of VR in education. The study also sought to promote environmental education and reduce the digital divide in remote regions. The immersive VR experience has the potential to enhance students' motivation through interactive exploration. By providing highly realistic visual effects, the VR360 system can expand learning opportunities and foster a deeper understanding of Tao Indigenous culture and the unique ecosystems of Orchid Island. It can improve learners' comprehension of cultural and ecological issues while stimulating engagement and active learning. Based on this aim, the study has addressed the following research questions:

1) What differences in learning effectiveness are observed in Indigenous culture and environmental education using the VR360 system across different ethnic backgrounds?
2) What impacts does the VR360 system have on elementary students' learning motivation toward Indigenous cultural heritage and environmental conservation, and how do these effects differ across diverse ethnic backgrounds?
3) How does the VR360 system affect cognitive load among elementary students of different ethnic backgrounds in Indigenous culture and environmental education?
4) How does technology acceptance of the VR360 system differ among elementary students of different ethnic backgrounds in Indigenous culture and environmental education?

To further ground this study theoretically, the research questions were guided within three major frameworks: Cognitive Load Theory (CLT), motivation theory, and the Technology Acceptance Model (TAM). CLT (Paas et al., 2003) provides a foundation for examining how the VR360 system influences learners' intrinsic, extraneous, and germane cognitive loads during spatial and ecological learning tasks. By analyzing differences in cognitive load between Indigenous and non-Indigenous students, the study explores whether immersive visualizations and contextual guidance can reduce unnecessary mental effort and enhance meaningful learning.

The concepts of intrinsic motivation and situational interest in motivation theory (Ryan & Deci, 2020) guide the investigation of how immersive cultural and ecological contexts influence students' learning motivation. The third research question specifically examines whether culturally embedded VR materials can affect students' cognitive load while maintaining engagement and fostering positive learning attitudes.

Finally, the TAM (Davis et al., 1989) is employed to evaluate students' perceived usefulness, perceived ease of use, and behavioral intention toward the VR360 system in learning activities. In connection with the second and fourth research questions, the TAM helps explain how learners' acceptance of VR-based instruction may vary depending on their prior experience with digital technology or the cultural relevance of the learning content provided.

Research Methodology

Learning Content

This study integrated Tao Indigenous culture and the ecological knowledge of Orchid Island to provide an immersive learning experience through systematic data collection and instructional content design. During the initial development phase, the research team conducted field investigations to document visual materials and collect data on local flora and fauna. Using the Unity game engine, these materials were organized into scene-based content aligned with a coherent learning framework. This approach allows learners to explore Tao Indigenous culture, the island's environmental features, and its unique ecosystems. The VR360 system immerses learners in the cultural and ecological landscapes of Orchid Island (Figure 1), creating an experience that closely simulates physical presence. By integrating panoramic imagery with an interactive interface, the system enables learners

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to engage with Tao local environments and explore them in depth, fostering deeper understanding of related cultural and ecological knowledge.

Figure 1
Orchid Island and Tao Tribal Villages as Primary Learning Content

Orchid Island, located off Taiwan's southeastern coast and officially part of Taitung County, is renowned for the distinctive Tao Indigenous culture and its rich natural landscapes. This study used the island's landscapes and Tao tribal villages as primary scenes, leveraging VR technology to present traditional semi-subterranean houses, simple yet architecturally striking, as well as the island's diverse ecological environments. Due to its unique climate and topography, different from Taiwan's main island, Orchid Island is home to numerous endemic plant and animal species. Both the Tao tribe and the island's natural features have been recognized by Taiwan's Ministry of Culture as potential candidates for World Heritage designation.

Flying fish play a central role in Tao life, shaping religious rituals, everyday practices, and social organization. Through VR experiences, learners can immerse themselves in the daily life of the Tao community, appreciate Tatala canoe craftsmanship, and engage with the distinctive flying fish culture. The VR360 system developed in this study also introduces scientific concepts, such as buoyancy in water and air, within these culturally and ecologically rich contexts.

In this study, Google Maps satellite imagery was used to plan VR observation points related to Indigenous culture and natural ecology. Learners can explore the landscapes while discovering the ecological mindset and environmental values embedded in Tao culture. The observation points and corresponding learning content include the Flying Fish Festival, the Tatala canoe, Tao villages, the Hongtou Forest Trail, semi-subterranean houses, and several other notable sites. Table 1 presents the names, themes, and descriptions of the VR360 observation points, outlining the learning content featured in each virtual scene. These scenes are designed to deepen learners' understanding of Tao culture and the unique ecology of Orchid Island.

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Table 1
VR360 System: Main Themes, Virtual Scenes, and Corresponding Descriptions

Theme	Virtual Scene	Description
Tao Culture	Yeyin Underground House	Traditional Tao dwellings developed in response to the island's hot and windy climate. These semi-subterranean structures consist of a main underground house, an adjacent workroom, and a terrace. Cultural elements such as backrest stones, traditional tableware, and rattan armor are also incorporated.
	Pavilion	Typically located in front of underground houses, these structures are supported by four sturdy pillars and thatched roofs. They serve as important summer resting spots and hubs for daily living and social interactions.
	Underground House: Level 1	The first level serves as the entrance to the main residence, which typically accommodates couples and their unmarried children. As children mature and establish their own families, the structure is expanded with additional doors and annexes, symbolizing family growth, labor capacity, and social status.
	Underground House: Level 2	This level is used for both sleeping and cooking. The kitchen is typically situated along one side, and years of indoor cooking gradually blacken the walls with soot. These soot-covered walls not only illustrate aspects of traditional life but also help deter pests.
	Underground House: Level 3	This level is used for storage and holds valuables and traditional armor. Flying fish caught during rituals are often hung here to dry.
	Lanyu Health Center	This is the island's only medical facility, offering continuous 24/7 healthcare services to more than 5,000 residents. It serves as a crucial center for emergency care, routine treatment, and public health support in this island.
	Lanyu Cultural Museum	A comprehensive Tao cultural park that showcases artifacts, handmade crafts, and traditional architecture. The park features an audiovisual exhibition area and an open grassland with reconstructed underground houses, providing an immersive cultural experience.
	Exhibition Area 1	Displays a variety of artistic works related to Tao culture and the ecology of Orchid Island, along with additional cultural and environmental artworks.
	Exhibition Area 2	Displays a variety of artistic works related to Tao culture and the ecology of Orchid Island, along with additional cultural and environmental artworks.
	Lanyu Airport	Features Tao totems and canoe-inspired architecture that highlight the island's unique cultural identity, welcoming visitors as they arrive.
	Yeyou Primary School	Decorated with Tao elements such as totems, canoes, and even a boat-shaped podium and sink, reflecting strong cultural integration.
	Old Lanyu Lighthouse	Located near Kaiyuan Port, this historical lighthouse was once vital for navigation. Now decommissioned, it remains a small scenic spot
	Dongching Bay: Tatala Canoe	The Tatala plays a vital role in both fishing and ceremonial practices. The launching ritual serves to unite families and strengthen social bonds, while during the Flying Fish Festival, the large canoe symbolizes cooperation and solidarity among different families.
	Dongching Bay: Flying Fish	The exhibit emphasizes the cultural significance of flying fish in Tao traditions, showcasing scenes of flying fish gracefully gliding above the sea.
Orchid Island	Twin Lions Rock	Located in the northeast, this volcanic formation—composed of andesite and basalt—resembles two lions gazing at each other and symbolizes affection and natural beauty.
	Warship Rock	A small, uninhabited islet off the northeast coast, shaped like a warship anchored at sea. This formation is a distinctive landmark, contributing to the region's geological diversity and cultural significance.
	Lover's Cave	A sea-eroded arch on a cape in Dongching Bay, renowned for its stunning sunrise views, natural beauty, and romantic legend.
	Dongching Hidden Cove	A natural seawater pool formed by coral reefs, ideal for swimming and playing in shallow, calm waters with diverse marine life and vibrant coral formations.
	Dragon Head Rock	A coral reef formation sculpted by wind and sea erosion, resembling a dragon's head and serving as a natural landmark for the local community.
	Yeyin Cold Spring	A freshwater spring emerges through cracks in coastal rocks, forming a cool spring surrounded by coral reefs—a hidden gem along the intertidal zone.
	Green Grassland	Located at the island's southern tip, this vast grassland was once cultivated but now serves as a scenic spot. The iron- and magnesium-rich soil supports a vibrant landscape ideal for sunset watching and ecotourism.

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System Development

The implementation of the VR360 system encompasses the development tools, design process, and system architecture. The learning content is grounded in Tao traditional culture and the ecological environment of Orchid Island, aiming to enhance students' motivation through immersive and interactive exploration and enabling them to discover Tao cultural heritage alongside related ecological knowledge. The following provides a detailed overview of each component. The VR360 system was developed using the Unity game engine, a versatile and widely adopted platform across mobile applications, web-based systems, education, simulation, healthcare, entertainment, and architecture, valued for its flexibility and powerful rendering capabilities. Development was carried out on a Microsoft Windows 11 platform, with Visual Studio 2022 used for C# programming and system integration. A suite of professional tools and software environments was employed to ensure seamless development and integration of the VR360 system. Unity served as the primary development platform due to its cross-platform compatibility and high-quality rendering capabilities, while Visual Studio 2022 facilitated efficient coding, debugging, and system integration.

The Google VR Software Development Kit (SDK) was selected for its optimized support of mobile-based VR applications, particularly low-cost solutions such as Google Cardboard. Through their integration, these tools enabled the creation of an immersive, interactive, and accessible learning experience tailored to elementary classrooms. Figure 2 presents a screenshot of the development interface within the Unity game engine. The 3D models used in the Unity environment were created with Blender 4.0, an open-source 3D graphics software widely employed for modeling, animation, game development, and visual effects. Figure 3 presents a 3D model of Orchid Island's flying fish integrated into the VR360 system, highlighting the visualization of cultural and ecological content for immersive learning experiences.

Figure 2
User Interface Developed with the Unity Game Engine

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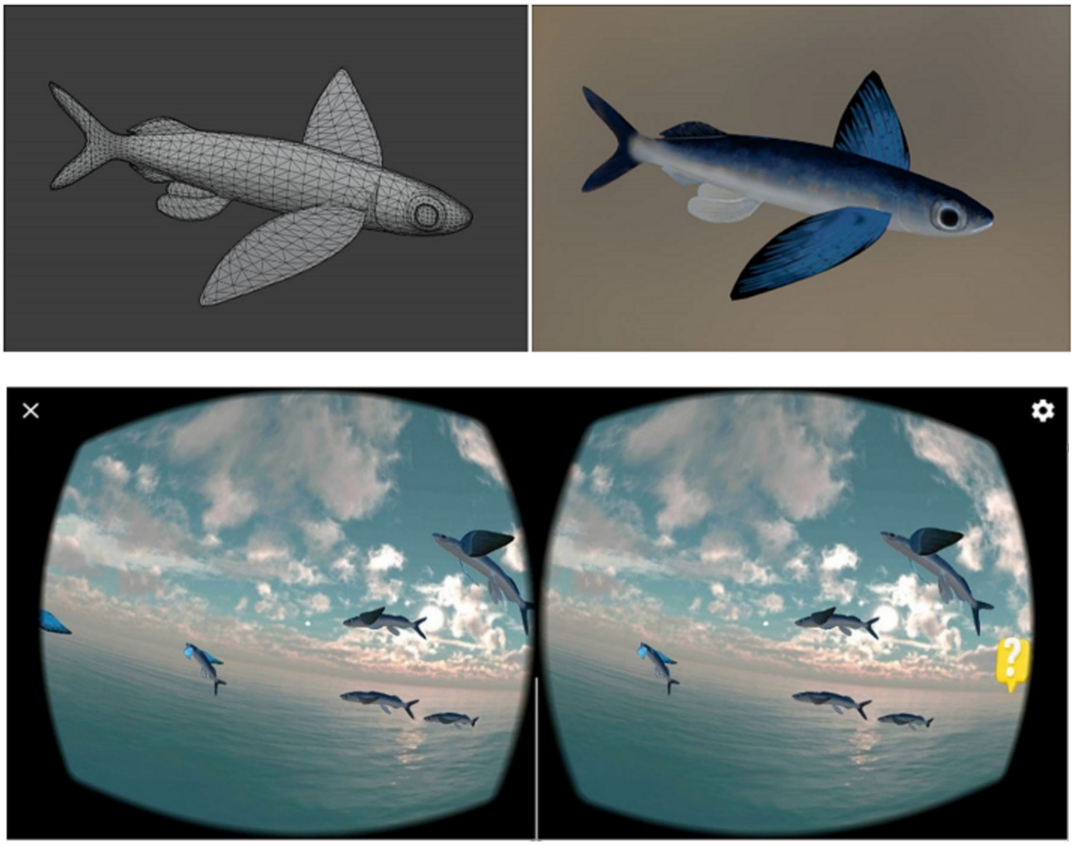
Figure 3
3D Models of Flying Fish and Visualization in the VR360 Environment



The VR360 system's user interface was designed using Adobe Creative Suite, with visuals and interface graphics created in Adobe Photoshop. Figure 4 provides an example of the interface along with the accompanying instructional text. An APK version of the VR360 system was developed for Android, allowing applications on mobile devices such as smartphones and tablets.

Figure 4
User Interface of the VR360 System and its knowledge points

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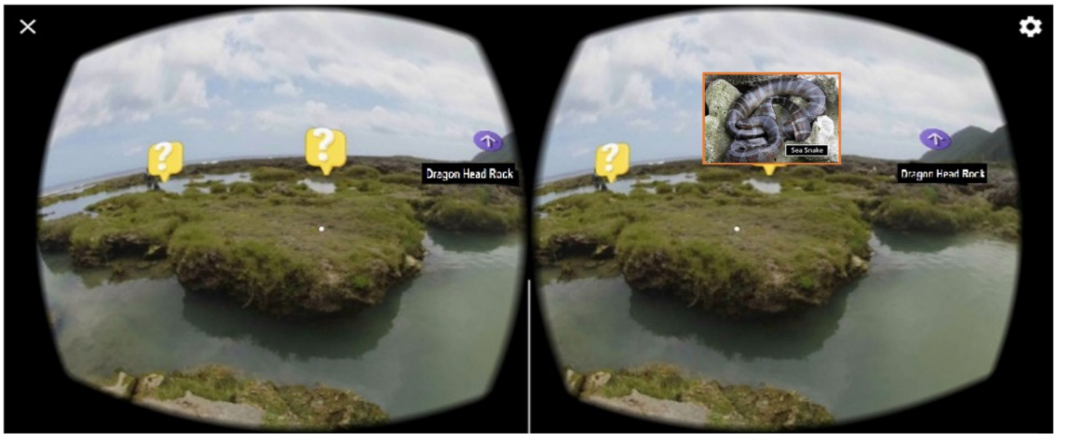
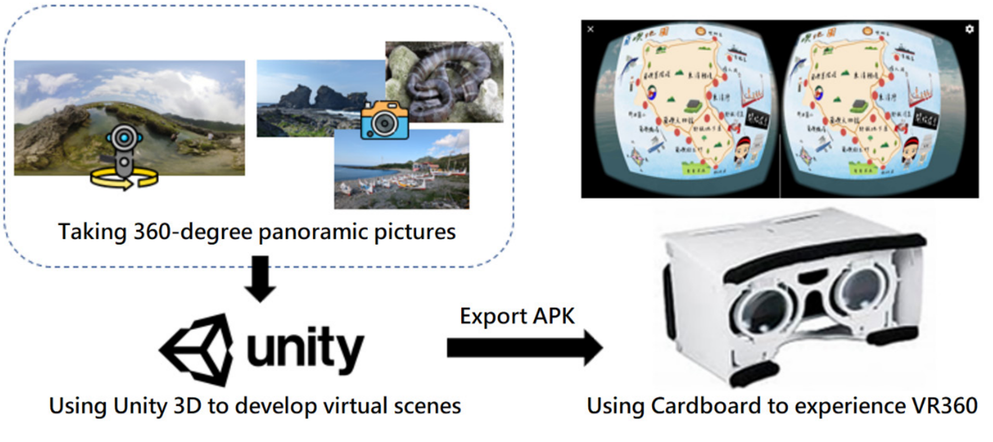
Learners can interact with the VR360 system using smartphones paired with Google Cardboard VR headsets. The system provides a 360-degree panoramic view, enabling them to explore real-world environments in an immersive manner. Figure 5 presents a virtual scene at Yeyin Cold Spring, where information hotspots introduce coastal species such as sea snakes. The stereoscopic images presented to each eye create a 3D visual effect to enhance the sense of immersion.

Figure 5
Stereoscopic View of a User Interacting with the VR360 System



The system integrates panoramic images captured with RICOH THETA V and Insta360 cameras, along with photos and videos of local ecology and wildlife taken using smartphones. These materials were organized and imported into the Unity game engine, where interactive elements, including flora and fauna, text, images, videos, 3D models, and UI/UX components, were incorporated. The Google VR SDK enables interactive feedback, allowing learners to trigger events and navigate through virtual scenes. The completed system is exported as an APK file and installed on Android smartphones. When paired with Cardboard VR headsets, the system delivers a simple, accessible, and immersive head-mounted VR experience. The VR360 development process is summarized in Figure 6.

Figure 6
Development and Implementation of the VR360 System



When learners launch the VR360 system, they encounter the main interface, which features an interactive map for exploring various observation points (Figure 7). By selecting a location, learners are immersed in the corresponding scene, and they can navigate the virtual environment clockwise or counterclockwise, following the actual geographic orientation of Orchid Island. At any point, learners can return to the main interface to select different scenes, enabling flexible exploration. This design enhances their understanding of spatial relationships across the island and supports the development of geographic knowledge and spatial awareness.

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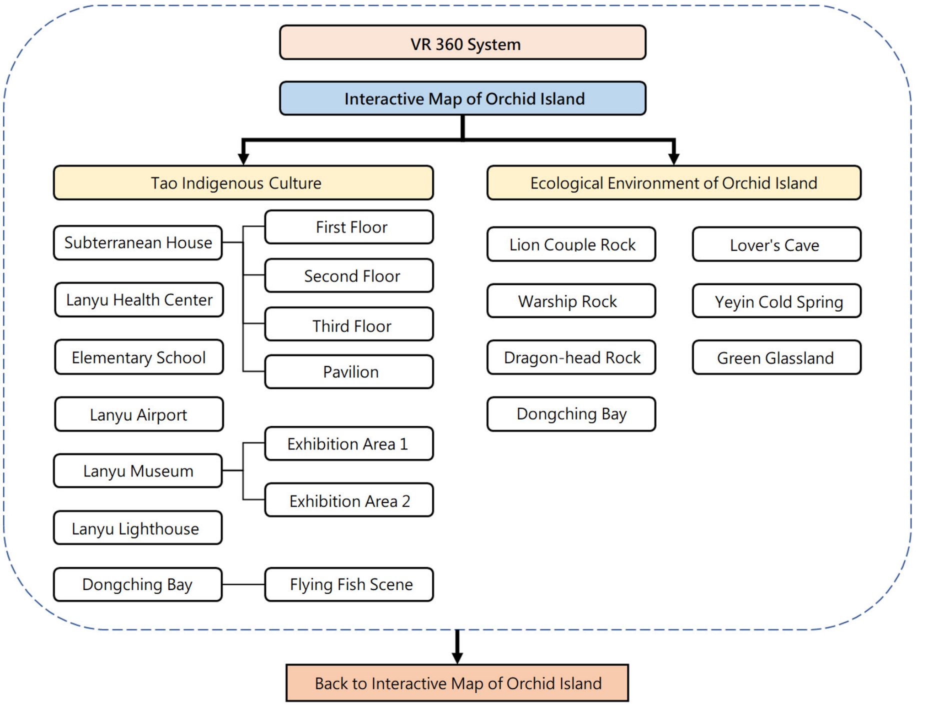
Figure 7
Interactive Map of Orchid Island with Exploratory Design

The VR360 system comprises 21 observation points, organized into 14 scenes highlighting Tao Indigenous culture and 7 scenes showcasing the diverse ecological environment of Orchid Island (Figure 8). The cultural module features important tribal and community sites, including the Subterranean House, Lanyu Health Center, Elementary School, Lanyu Airport, Lanyu Museum, Lanyu Lighthouse, and Dongching Bay, as well as detailed interior views of multi-level exhibition spaces, a pavilion, and the culturally significant Flying Fish scene. The ecological module presents notable natural landmarks such as Lion Couple Rock, Warship Rock, Dragon-head Rock, Lover's Cave, Yeyin Cold Spring, Green Grassland, and the scenic Dongching Bay.

Figure 8
Cultural and Ecological Virtual Scenes in the VR360 System



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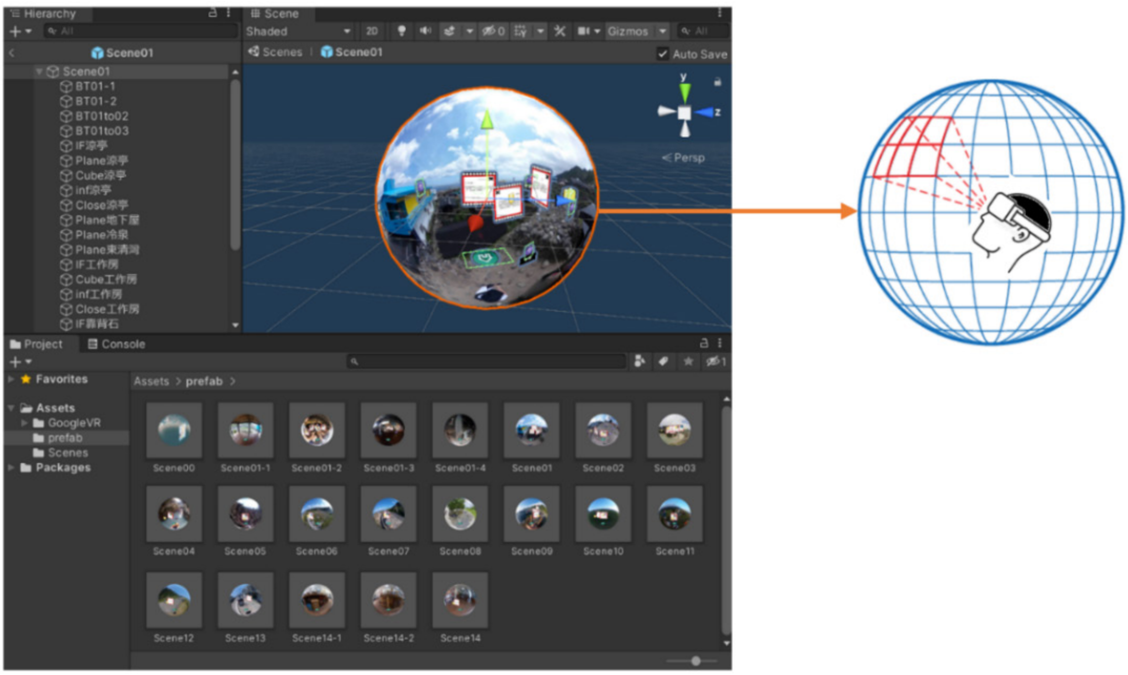
These virtual scenes offer learners a rich, detailed, and immersive experience that integrates cultural heritage with the island's environmental knowledge. By exploring different scenes, students can engage with traditional practices, observe native biodiversity, and gain a deeper understanding of how the Tao people interact with and adapt to their environments. This comprehensive approach is designed to foster cultural appreciation, environmental awareness, and sustained learning engagement. To reduce loading times and optimize system performance during operation, the virtual scenes were segmented by size. As we can see in Figure 9, there are 21 spheres, each representing a virtual scene in the VR360 system. Learners can move from one scene to another using the connection link to complete the exploration. The scene depicting the flying fish at Dongching Bay was developed as a standalone module due to its large file size and more complex interactive animations, while the smaller spheres represent the remaining scenes described above.

Figure 9
Segmentation of Virtual Scenes to Minimize Loading Time



Within each virtual scene, learners can access additional information by gazing at a question-mark icon for one second, which activates the corresponding content. For instance, in the Dongching Bay scene, learners can explore Orchid Island's ecological features alongside Tao Indigenous cultural practices by navigating virtual experiences such as the Tatala Launching Ceremony and the Flying Fish Festival. They can also observe the "Eyes of the Boat" motif—a red-and-black sunray design on traditional canoes that symbolically guides voyages and prevents misfortune (Figure 10).

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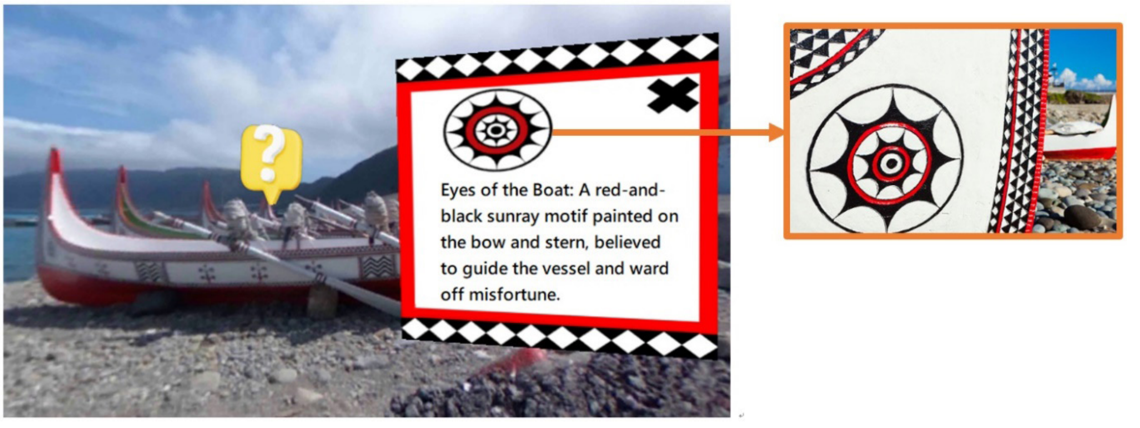
Figure 10
Question-Mark Icon as a Trigger for Accessing Knowledge Points



The VR360 system also offers intuitive navigation features (Figure 11), allowing learners to freely explore individual scenes or return to the main menu and the interactive tour map (Figure 12). These features support deeper multisensory learning by providing visual, auditory, and textual information on biodiversity and environmental features. Students can complete guided exploration tasks using worksheets, reinforcing content retention and further enhancing their understanding of Orchid Island's ecological environment and Tao Indigenous cultural heritage.

Figure 11
Arrow Icon for Navigating to Another Virtual Scene

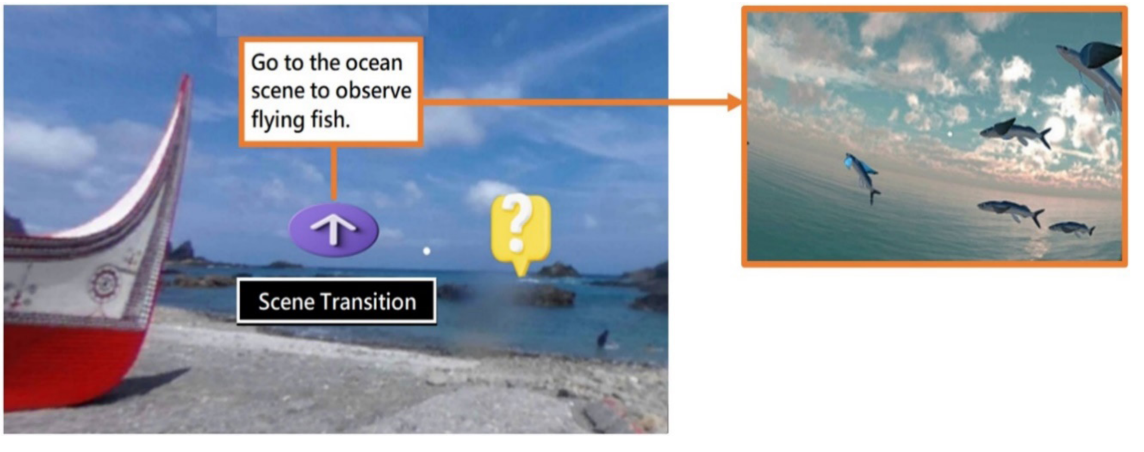
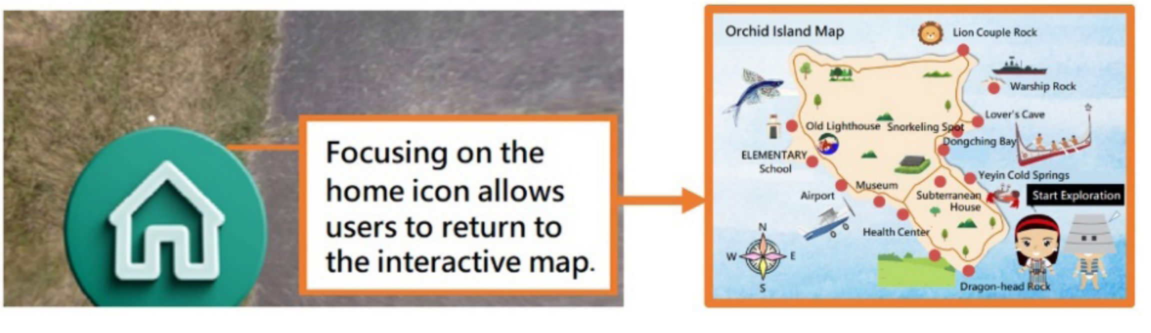


Figure 12
Home Icon for Returning to the Main Menu



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Experimental Design

An educational experiment was conducted to examine the effects of the VR360 system on learning outcomes, motivation, cognitive load, and technology acceptance. The experiment involved 64 students from grades three to six across four elementary schools in northern Taiwan. Participants were selected based on school enrollment and willingness to participate in the study, with informed consent obtained from their parents or guardians. Both Indigenous and non-Indigenous students were included to represent the target population, minimize potential sampling bias, and allow for balanced comparisons between groups. Students were not randomly assigned; instead, they were classified according to their self-identified ethnic backgrounds as Indigenous or non-Indigenous. This natural grouping enabled a systematic examination of potential differences in learning outcomes, motivation, cognitive load, and technology acceptance across ethnic backgrounds.

A nonequivalent groups pretest-posttest design was employed, dividing participants into an Indigenous group (n = 33) and a non-Indigenous group (n = 31). Both groups engaged in learning activities using the VR360 system to explore Tao Indigenous culture and the ecological environment of Orchid Island. The experimental procedure followed a structured 100-minute sequence. Initially, participants completed a pretest to assess baseline knowledge, followed by an introduction to the VR360 system, during which students were familiarized with its navigation, interactive features, and learning objectives. Figure 13 shows students interacting with the VR360 system following the system introduction. They explored Tao cultural heritage and ecological diversity while completing a guided worksheet designed to support observation and reflection.

Figure 13
Elementary Students Learning with the VR360 System

After the exploratory learning activity, students completed a posttest to assess knowledge acquisition and learning gains. The experiment concluded with a questionnaire survey measuring learning motivation, cognitive load, and technology acceptance (Figure 14). This structured design ensured that both groups followed the same instructional sequence, allowing for direct comparison of learning outcomes and student attitudes across all measured variables.

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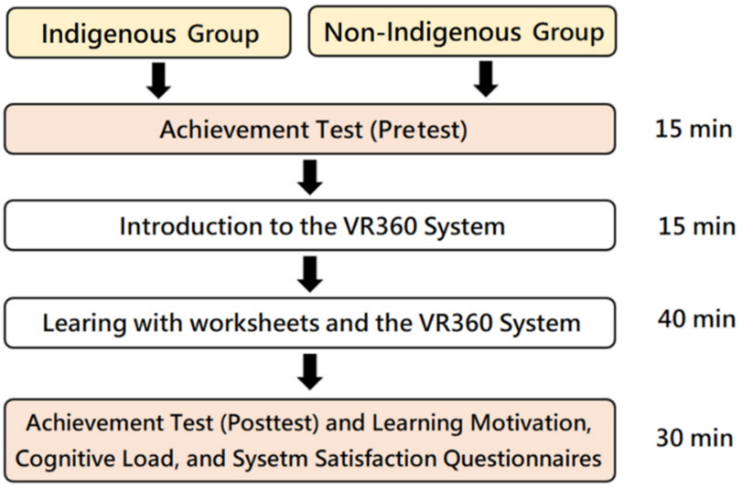
Figure 14
Experimental Procedure Implemented for Both Groups



The introduction to the VR360 system was guided by a PowerPoint presentation that highlighted the system's key functions, accompanied by interactive questioning to encourage student participation. To establish contextual understanding, students were first provided with foundational knowledge of Tao culture and the ecological environment of Orchid Island. During the VR360 learning experience, students explored virtual scenes and completed worksheet-based tasks designed to guide information acquisition. These activities supported a comprehensive understanding of both Tao culture and Orchid Island's ecological environment. Table 2 summarizes the experimental procedure, detailing the group, time allocation, activities, and corresponding measurements at each stage.

Table 2
Experimental Stages Showing Group, Duration, Activity, and Measurements in Each Stage

Stage	Group	Time	Activity	Measurement
Pretest	Indigenous & Non-Indigenous	15 min	Achievement test (pretest)	Knowledge baseline
Introduction	Indigenous & Non-Indigenous	15 min	Introduction to the VR360 system, covering navigation, interactive features, and learning objectives	None
VR360 Exploration	Indigenous & Non-Indigenous	40 min	Learning with VR360 system and worksheets: Tao culture and Orchid Island ecology	Worksheet completion and observation
Posttest & Questionnaires	Indigenous & Non-Indigenous	30 min	Achievement test (posttest); learning motivation, cognitive load, and system satisfaction questionnaires	Knowledge gains, motivation, cognitive load, and system satisfaction

This study aimed to examine the influence of students' ethnic backgrounds on learning outcomes, learning motivation, and cognitive load. Figure 15 presents a conceptual diagram illustrating the experimental design and the relationships among the measured variables.

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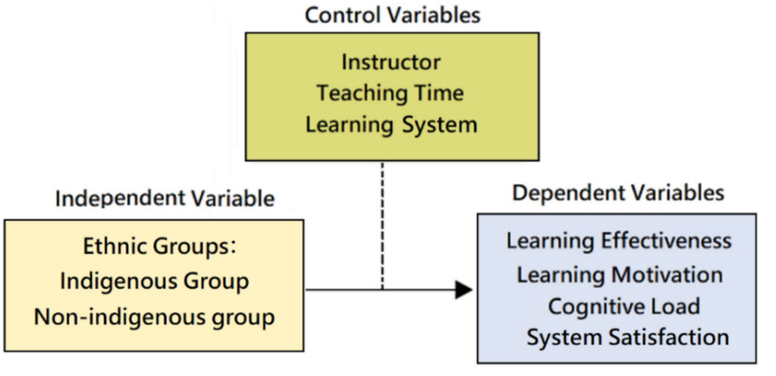
Figure 15
Conceptual Diagram Illustrating Experimental Design and Relationships among Variables



This study employed a nonequivalent groups pretest–posttest design to compare learning performance between Indigenous and non-Indigenous students, with both groups receiving the VR360 intervention and no separate control group included. Although this design allowed for the examination of differences in learning outcomes, learning motivation, cognitive load, and technology acceptance between the two groups, it limited the ability to draw strong causal conclusions regarding the effects of the VR360 system. Consequently, the findings should be interpreted as reflecting associations and group differences rather than definitive causal relationships.

Instruments

Four instruments were employed in this study to collect data for analyzing students' learning outcomes: an achievement test, scales measuring learning motivation and cognitive load, and a questionnaire evaluating system satisfaction.

- **Achievement Test:** An achievement test aligned with the learning content was developed to assess differences in learning effectiveness between the two groups before and after instruction. The test comprised 20 multiple-choice items with four answer choices each, reviewed by two experienced teachers to ensure reliability and alignment with the learning objectives.
- **Learning Motivation Scale:** To assess participants' learning motivation after the intervention and compare results across the two ethnic groups, this study employed the 5-point Likert scale developed by Hwang et al. (2013), ranging from "strongly disagree" (1) to "strongly agree" (5), with higher scores indicating greater motivation.
- **Cognitive Load Scale:** To examine potential differences in cognitive load, this study used a six-item scale adapted from Krieglstein et al. (2023). Items are rated on a 5-point Likert scale from "strongly disagree" (1) to "strongly agree" (5), with lower scores indicating lower cognitive load. The scale assesses intrinsic cognitive load, reflecting the perceived difficulty of learning tasks, and extraneous cognitive load, reflecting the mental demands of the instructional method.
- **System Satisfaction Questionnaire:** Based on the extended TAM proposed by Zhou et al. (2022), the questionnaire measured students' satisfaction with the VR360 system, including Perceived Usefulness, Perceived Ease of Use, and Intention to Use, using a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree), with higher scores indicating greater satisfaction.

The validity of all instruments was confirmed by two experts in related fields: an elementary school teacher and a VR360 content designer. Reliability was evaluated using Cronbach's alpha to measure internal consistency. The learning motivation and cognitive load scales demonstrated satisfactory reliability, with Cronbach's alpha coefficients of 0.79 and 0.85, respectively. The system satisfaction questionnaire showed high internal consistency (Cronbach's alpha = 0.94), indicating that the items reliably measured the intended construct.

Data analysis was conducted using SPSS 30, a widely adopted statistical software package for experimental research. All data were carefully recorded and coded to ensure accuracy. Preliminary analyses included descriptive statistics, such as means and standard deviations, to summarize experimental outcomes. Paired-samples t-tests,

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independent-samples t-tests, and ANCOVA were used to analyze within-group and between-group differences, and results were interpreted using statistical significance to draw reliable and meaningful conclusions.

Statistical Methods

This study employed statistical analyses using SPSS software to examine learning effectiveness, learning motivation, cognitive load, and system satisfaction among elementary students who engaged with the VR360 system to explore Tao Indigenous culture and the ecological environment of Orchid Island. The analytical methods are described as follows:

- **Descriptive Statistics:** This method summarizes the main characteristics of the data, including means and standard deviations. It provides insights into the distribution and variability of test scores, highlighting overall patterns and supporting conclusions regarding the effects of the VR360 system on learning outcomes.
- **Paired-Samples t-Test:** This method compares two related sets of data—such as pretest and posttest scores within the same group—to determine whether significant changes in performance occurred following the intervention.
- **Independent-Samples t-Test:** This method examines differences in mean scores between groups (e.g., Indigenous versus non-Indigenous students). It produces both a t-value and a p-value to evaluate whether observed differences are statistically significant and meaningful.
- **One-Way Analysis of Covariance (ANCOVA):** This technique was used to control for initial performance differences by adjusting for potential confounding variables in group comparisons. It provides a more rigorous and reliable evaluation of the effects of the VR360 system on learning outcomes across different ethnic groups.

Research Results

Learning Effectiveness

Table 3 presents the descriptive statistics for the pretest and posttest scores of both groups, including means and standard deviations. The Indigenous group had a pretest mean of 52.27, which increased to 64.70 following the VR intervention. In comparison, the non-Indigenous group started with a higher pretest mean of 60.16, which rose to 76.94 after intervention. These results indicate that while both groups demonstrated learning gains after using the VR360 system, the non-Indigenous group showed greater improvement in learning outcomes. The statistical significance of these improvements can be further assessed using paired samples t-tests.

Table 3
Descriptive Statistics of Pretest and Posttest Results for Both Groups

Group	Pretest *M*	Pretest *SD*	Posttest *M*	Posttest *SD*
Indigenous students (n = 33)	52.27	20.73	64.70	20.99
non-Indigenous students (n = 31)	60.16	15.63	76.94	16.11

Notably, the Indigenous group exhibited higher standard deviations in the pretest and posttest, indicating greater individual differences in learning achievement within this group. This variation may reflect differences in prior knowledge, reading comprehension, cultural familiarity, and engagement levels among Indigenous students, resulting in more pronounced disparities in learning outcomes after the intervention. In contrast, the non-Indigenous group had smaller standard deviations, suggesting more consistent performance and lower variability. A higher standard deviation is not inherently problematic; rather, it highlights heterogeneity in learning achievement within a group. These findings reveal the differential impact of the VR360 system across ethnic backgrounds and suggest that future instructional design should account for student diversity by incorporating more personalized and adaptive strategies to enhance learning effectiveness and promote educational equity.

Paired samples t-tests were conducted to determine whether learners in each group demonstrated significant improvements in learning achievement after using the VR360 system. As shown in Table 4, both groups exhibited

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statistically significant gains, with the Indigenous group improving notably ($p < .001$) and the non-Indigenous group also showing significant progress ($p < .001$). The results indicate that both groups of students made significant improvements in learning about Tao culture and the ecological environment of Orchid Island. The greater variability within the Indigenous group highlights the diversity of learning outcomes and suggests the need for differentiated support to ensure all learners benefit from immersive cultural and ecological instruction.

Table 4

Paired Samples t-Test Results for Learning Achievement in Both Groups

Group	*M*	*SD*	*t*	Cohen's *d*	η^2	*p*
Indigenous students	12.42	12.51	5.71	.99	.51	< .001***
Non-Indigenous students	16.77	10.21	9.15	1.64	.74	< .001***

*** $p < .001$

Both groups demonstrated strong learning gains following the VR360 instruction, with effect sizes ranging from large to very large. The non-Indigenous group exhibited a greater effect (Cohen's $d = 1.64$), indicating that the VR360 system was particularly impactful for students less familiar with Tao culture. Similarly, the Indigenous group also showed substantial improvement (Cohen's $d = 0.99$), suggesting that even learners with prior cultural familiarity benefited from the VR learning experience. The greater improvement among non-Indigenous students suggests that the realistic environment provided rich contextual cues and immersive experiences that facilitated understanding of unfamiliar cultural and ecological concepts. In contrast, the smaller yet significant gains among Indigenous students reflect prior familiarity with the content, leaving less room for measurable improvement. In addition, the higher variability within the Indigenous group reflects diverse levels of prior knowledge and individual engagement, reflecting the importance of considering learners' cultural backgrounds when designing VR-based teaching materials.

A one-way ANCOVA was conducted to examine differences in posttest scores between the two groups while controlling for pretest performance. Assumptions for the analysis, including normality, homogeneity of variances, and linearity, were evaluated to guarantee that the assumption of homogeneous regression slopes was satisfied. Levene's test for equality of variances was non-significant ($p = 0.164 > .05$, $R^2 = 0.691$), confirming that variance homogeneity was met. In the ANCOVA, pretest scores served as the covariate, group membership (Indigenous vs. non-Indigenous) as the independent variable, and posttest scores as the dependent variable.

As shown in Table 5, the group effect was statistically significant, $F = 4.067$, $p = .048 < .05$, indicating that the ethnic group membership significantly influenced posttest performance after controlling for pretest scores. Consistent with the paired samples t-test results, both Indigenous and non-Indigenous students achieved significant improvements in learning about Tao Indigenous culture and Orchid Island's ecological environment. However, non-Indigenous students exhibited a higher level of improvement than Indigenous students. This difference persisted even after adjusting for pretest performance, suggesting that the VR360 system produced differential impacts across ethnic groups, with non-Indigenous students obtaining greater benefit from the intervention.

Table 5

ANCOVA Results Comparing Learning Achievement between the Two Groups

Source	*SS*	*df*	*F*	*p*	ηp^2
Pretest Score	14384.841	1	117.059	< .001***	.657
Group	499.732	1	4.067	.048*	.062
Error	7496.000	61			
Total	343500.000	64			

*$p < .05$, ***$p < .001$

Previous research has suggested that family background and ethnicity can influence the academic performance of Indigenous students. Factors such as lower parental expectations, limited access to after-school tutoring, and reduced availability of learning resources due to the digital divide may contribute to these disparities. Addition-

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ally, teacher expectations regarding student achievement often differ between Indigenous and non-Indigenous schools, which can impact students' learning motivation. Collectively, these interrelated factors may help explain why non-Indigenous students demonstrated greater gains in learning achievement in the present study.

Learning Motivation

This study used a 5-point Likert scale to assess learning motivation among Indigenous and non-Indigenous students after interacting with the VR360 system to explore Tao Indigenous culture and Orchid Island's natural ecology. An independent samples t-test was conducted to compare the mean motivation scores of the two groups and assess whether any differences were statistically significant. As shown in Table 6, the Indigenous group had a mean score of 4.54, compared to 4.28 for the non-Indigenous group, indicating a slightly higher motivation level among Indigenous students. The effect size was small to moderate (Cohen's $d = .40$, $\eta^2 = .04$), suggesting a modest, non-significant trend toward higher motivation in the Indigenous group. Given the two motivation subscales (Intrinsic and Extrinsic), a Bonferroni correction was applied to control for Type I errors, setting the adjusted significance level at $\alpha = .05/2 = .025$. Despite this adjustment, the independent samples t-test indicated no statistically significant difference ($p = .119 > .025$), suggesting that learning motivation was comparable between Indigenous and non-Indigenous students.

Table 6
Independent Samples t-Test on Learning Motivation for Both Groups

Group	*M*	*SD*	*t*	*p*	Cohen's *d*	η²
Indigenous	4.54	.641	1.582	.119	.40	.04
non-Indigenous	4.28	.650				

Analysis of learning motivation, both intrinsic and extrinsic, revealed no significant differences between the two groups overall (Table 7). However, at the item level, a significant difference was observed for Question 3: "After the course, I would like to learn more about Indigenous culture and environmental ecology" ($p = .009 < .01$). The Indigenous group reported a higher mean score ($M = 4.70$) compared to the non-Indigenous group ($M = 4.19$), indicating a stronger interest in further exploring related cultural and ecological topics beyond the course.

Table 7
Independent Samples t-Test Results for Intrinsic and Extrinsic Motivation

Motivation	Group	*M*	*SD*	*t*	*p*
Intrinsic	Indigenous	4.62	.662	1.578	.120
	non-Indigenous	4.34	.717		
Extrinsic	Indigenous	4.46	.716	1.387	.171
	non-Indigenous	4.23	.631		

Cognitive Load

A 5-point Likert scale was used to measure the cognitive load of Indigenous and non-Indigenous students while interacting with the VR360 system. An independent samples t-test was conducted to compare the mean cognitive load scores between the two groups and assess whether the differences were statistically significant. As shown in Table 8, Indigenous students reported a higher cognitive load ($M = 3.48$) than the non-Indigenous group ($M = 2.68$). The effect size was substantial (Cohen's $d = .72$, $\eta^2 = .12$), indicating a meaningful difference in perceived mental effort. Although Indigenous students were familiar with the learning content, they encountered additional cognitive demands when navigating the VR interface or interpreting digital representations of familiar contexts. After applying a Bonferroni correction for the two comparisons (adjusted $\alpha = .025$), the independent samples t-test indicated a significant difference in cognitive load between the two groups ($p = .006 < .025$).

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Table 8
Independent Samples t-Test Comparing Cognitive Load between the Two Groups

Group	*M*	*SD*	*t*	*p*	Cohen's d	η²
Indigenous	3.48	1.358	-2.850	.006*	.72	.12
non-Indigenous	2.68	.851				

*$p < .025$

To gain deeper insights, this study further examined the dimensional aspects of cognitive load—specifically intrinsic and extraneous load—to better understand their impacts on learning. As shown in Table 9, the Indigenous group reported a higher intrinsic cognitive load ($M = 3.72$) compared to the non-Indigenous group ($M = 3.01$). Similarly, the extraneous cognitive load was higher for the Indigenous group ($M = 3.24$) than for the non-Indigenous group ($M = 2.34$). Independent samples t-tests revealed statistically significant differences between the two groups for both intrinsic load ($p = .021 < .05$) and extraneous load ($p = .004 < .01$). These findings indicate notable differences in how students processed the learning materials, which may reflect variations in prior knowledge, familiarity with the content, or the cultural relevance of the VR360 learning experience.

Table 9
Independent Samples t-Test for Intrinsic and Extraneous Cognitive Load

Cognitive Load	Group	*M*	*SD*	*t*	*p*	Cohen's *d*	η²
Intrinsic	Indigenous	3.72	1.339	2.372	.021*	.60	.083
	non-Indigenous	3.01	1.009				
Extraneous	Indigenous	3.24	1.463	3.005	.004**	.76	.127
	non-Indigenous	2.34	.871				

*$p < .05$, **$p < .01$

The analysis revealed significant group differences in both intrinsic and extraneous cognitive load. Indigenous students reported higher intrinsic ($d = .60$, $\eta^2 = .083$) and extraneous load ($d = .76$, $\eta^2 = .127$), suggesting they experienced greater mental effort and cognitive processing demands in the immersive learning experience. These differences may be attributable to variations in familiarity with digital learning environments or prior experience with VR360 technology.

Technology Acceptance

In this study, the Technology Acceptance Model (TAM) was employed to evaluate participants' satisfaction with the VR360 system. Table 10 summarizes the descriptive statistics and significance findings from the TAM questionnaire. Most item means exceeded 4.0, indicating that learners were generally "satisfied" to "very satisfied" with the VR360 exploration of Tao culture and the natural ecology of Orchid Island, reflecting a high level of satisfaction.

Regarding technology acceptance, the Indigenous group had a higher overall mean score ($M = 4.45$) than the non-Indigenous group ($M = 4.18$), suggesting that both groups held positive perceptions of the VR360 system. Examination of the individual subscales revealed that the Indigenous group reported higher scores across all three dimensions: perceived usefulness ($M = 4.48$), perceived ease of use ($M = 4.45$), and intention to use the system ($M = 4.39$). In comparison, the non-Indigenous group reported slightly lower scores for perceived usefulness ($M = 4.25$), perceived ease of use ($M = 4.09$), and intention to use ($M = 4.20$). These results indicate that Indigenous students demonstrated a marginally higher level of technology acceptance and satisfaction with the VR360 system than their non-Indigenous peers. Since the TAM questionnaire included three subscales, a Bonferroni correction was applied to control for Type I errors, setting the adjusted significance level at $\alpha = .05/3 = .017$. The independent-samples t-test results, however, showed no statistically significant differences between groups at this adjusted level ($p = > .017$), suggesting that both Indigenous and non-Indigenous students exhibited comparable levels of technology acceptance.

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Table 10
Descriptive Statistics and Significance of the System Satisfaction Questionnaire

Dimension	Indigenous Group		Non-Indigenous Group		*p*	Cohen's *d*
	M	*SD*	*M*	*SD*		
Perceived Usefulness	4.48	0.830	4.25	0.721	.248	.30
Perceived Ease of Use	4.45	0.789	4.09	0.720	.058	.48
Intention to Use	4.39	0.738	4.20	0.724	.304	.26
Overall Acceptance	4.45	0.740	4.18	0.663	.134	.38

The mean scores indicate that the Indigenous group generally exhibited higher technology acceptance than the non-Indigenous group. Notably, a statistically significant difference was observed for Question 10, "It is easy for me to learn using the VR360 system" ($p = .028 < .05$). This difference may be attributed to the alignment between the learning content and Indigenous students' cultural background, which can foster stronger learning motivation and enhance their acceptance of the VR360 system. Additionally, factors related to the digital divide—such as limited access to internet resources, computer hardware, or digital literacy—may also play an essential role. When adequate technical support and instructional guidance are provided, Indigenous students are likely to demonstrate higher motivation and greater acceptance of educational technology such as VR360.

Discussion

This study examined the impacts of the VR360 system, which integrates immersive technology with Tao Indigenous culture and Orchid Island's ecological environment, on elementary students' learning outcomes, including learning achievement, learning motivation, cognitive load, and system satisfaction. The main findings are summarized as follows:

Both groups showed significant improvement after using the VR360 system, with non-Indigenous students outperforming Indigenous students.

The VR360 system significantly enhanced learning achievement for both Indigenous and non-Indigenous students, demonstrating its effectiveness in conveying cultural and ecological knowledge. On average, Indigenous students' scores increased by 12.42 points, while non-Indigenous students improved by 16.77 points. Although both ethnic groups achieved substantial gains, ANCOVA results revealed a statistically significant difference in posttest performance after controlling for pretest scores ($p = .048 < .05$), indicating that non-Indigenous students continued to outperform their Indigenous peers. This greater improvement may reflect higher familiarity with digital tools and lower cognitive load among non-Indigenous students. Nonetheless, the notable progress among Indigenous students suggests that culturally relevant content and visually engaging VR interfaces can effectively support knowledge acquisition and conceptual understanding.

Both ethnic groups exhibited high learning motivation with no significant differences, although Indigenous students showed greater interest in learning about their traditional culture.

The VR360 system positively stimulated learning motivation in both groups. No statistically significant differences were observed in overall motivation or its intrinsic and extrinsic components. However, a significant difference emerged for one item: "After the course, I like to learn more about Indigenous culture and environmental ecology" ($p < .01$). The Indigenous group scored higher than the non-Indigenous group, indicating that culturally relevant content encouraged Indigenous students to further explore their culture and ecological environment beyond the course.

This motivational difference appears to result from an interaction between cultural identification and instructional design. For Indigenous students, the culturally relevant content fostered a sense of identity and pride, enhancing intrinsic motivation. At the same time, the immersive and interactive VR experience increased situational interest and engagement for all students. Thus, motivation was strengthened by both cultural resonance and experiential learning.

Indigenous students experienced higher cognitive load than non-Indigenous students, in both intrinsic and extraneous dimensions.

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Indigenous students reported higher overall cognitive load compared to their non-Indigenous peers. Specifically, they indicated greater intrinsic load on items such as "I find it difficult to answer the questions in the course" (p = .012), "I feel that the instructions are unclear" (p = .030), "I feel that there is a lot of irrelevant information that distracts me" (p = .003), and "The teaching method and course design make it unnecessarily complex and difficult" (p = .028). These results may reflect limited experience with digital tools and additional cognitive demands of processing new information in a VR learning environment. In contrast, non-Indigenous students encountered lower cognitive load, which may have contributed to their larger learning gains.

Cognitive load consists of intrinsic, extraneous, and germane components. The higher cognitive load for Indigenous students may stem from increased intrinsic load due to the cultural depth and contextual richness of the learning materials, requiring more effort to connect traditional knowledge with VR representations. Extraneous load may also have been higher due to unfamiliarity with VR navigation. Despite these challenges, strong cultural identification and interest likely promoted germane load, supporting meaningful learning under increased cognitive demands.

Although Indigenous students reported higher cognitive load while using the VR360 system, this does not necessarily indicate difficulty or confusion. The higher cognitive load may partially reflect deeper cognitive engagement and active processing, particularly given these students' stronger motivation and cultural connection to the content. Research on cognitive load theory suggests that when learners are highly motivated and find the content personally relevant, increased cognitive effort can correspond to meaningful learning rather than overload (Wang et al., 2025). In this context, the immersive VR environment, combined with culturally relevant material, may have encouraged Indigenous students to invest greater mental effort in exploring and understanding the content, enhancing engagement and learning outcomes despite the higher cognitive demands. This interpretation aligns with findings that well-designed, immersive learning environments can promote sustained attention and motivation even when cognitive load is elevated (Zu et al., 2020).

Both groups exhibited high levels of technology acceptance for the VR360 system.

The Indigenous group reported slightly higher overall and dimensional mean scores than the non-Indigenous group; however, no significant differences were observed within the two groups. Notably, for the item "Learning with the VR360 system is easy for me," Indigenous students reported significantly higher perceived ease of use (p = .028). This suggests that, despite experiencing higher cognitive load, Indigenous students considered the VR360 system with Cardboard VR goggles as accessible and effective learning tools. Prior research suggests that well-designed immersive VR environments can maintain learner motivation and usability even when cognitive demands are elevated, particularly when content relevance and contextual authenticity are high (Makransky & Petersen, 2021; Parong & Mayer, 2018). These findings suggest that cultural relevance plays a critical role in shaping learners' perceptions of usability in immersive learning environments. In addition, the first-person perspective and experiential nature of VR may have aligned closely with Indigenous learners' experiential and place-based learning traditions, increasing perceived accessibility and meaningfulness of the learning experience.

Limitations of this study

This study has some limitations. First, the sample was relatively small and drawn from only four elementary schools in northern Taiwan, limiting generalizability and broader applicability. Second, the intervention period was short, capturing only immediate learning effects without assessing long-term retention or sustained motivation. Third, a novelty effect may have influenced engagement, as many students experienced VR learning for the first time. Given the small sample size and limited geographic scope of the current study, the findings should be interpreted with caution and not generalized to broader populations. Future research should involve larger and more diverse samples, including students from different regions, school types, age groups, extended interventions, and longitudinal designs. Expanding the study in this way would allow for more robust comparisons, help account for contextual and cultural variability, and provide stronger evidence regarding the educational impact of the VR360 system across diverse learning environments.

The VR360 system can be incorporated into classroom instruction with limited resources by using affordable VR tools, such as Google Cardboard and mobile devices. It is suitable for small-group or rotation-based learning, enabling multiple students to share VR equipment efficiently. Teachers can integrate VR lessons with existing science, social studies, or environmental curricula, supported by pre- and post-VR discussions, worksheets, and reflective activities. The immersive experience helps bridge abstract concepts and real-world understanding, enhancing student engagement and cultural appreciation without requiring expensive technological infrastructure.

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Conclusions and Implications

Indigenous peoples' commitment to ecological conservation is deeply rooted in the ecological environments that sustain their livelihoods. They possess extensive knowledge of sustainable practices that foster harmonious coexistence with nature. This study integrated VR technology with Indigenous cultural perspectives and conservation concepts to enhance the effectiveness of environmental education while boosting learners' motivation and engagement. The primary goal was to improve environmental learning outcomes and simultaneously address the persistent digital divide between Indigenous and non-Indigenous students in rural and urban schools.

The present study offers both scientific and practical contributions. Scientifically, it advances understanding of how culturally contextualized VR360 experiences influence learning achievement, motivation, cognitive load, and technology acceptance across diverse ethnic groups. The findings enrich applications of Cognitive Load Theory and the Technology Acceptance Model within cross-cultural educational contexts. Practically, this study provides guidance for integrating affordable VR tools, such as mobile phones and Google Cardboard, into classroom teaching. Teachers can use VR content to enhance learning engagement and cultural understanding, while policymakers can support equitable access to immersive learning technologies, helping Indigenous students to reduce the digital divide and promote inclusive education in remote regions.

This research has significant international relevance by demonstrating how low-cost cardboard VR can integrate Indigenous cultural heritage with environmental education, offering an affordable and practical model for culturally responsive, immersive learning worldwide. It highlights strategies to mitigate the digital divide in under-resourced communities, promoting educational equity across diverse contexts. By combining VR360 technology, Indigenous culture, and ecology, this study provides insights into fostering global awareness of local traditions and sustainable practices. The research findings can inform policymakers, educators, and researchers seeking scalable, inclusive approaches to STEM and environmental education, emphasizing the value of culturally grounded, technology-enhanced learning for diverse student populations globally.

The analysis results revealed that both Indigenous and non-Indigenous students showed significant improvements in learning outcomes after using the VR360 system to explore Tao culture and Orchid Island's natural environment. However, Indigenous students experienced higher cognitive load than their non-Indigenous peers, limiting their performance gains and led to greater improvements among non-Indigenous students. Despite this, Indigenous students showed a notable increase in learning motivation, expressing stronger engagement in further exploring Indigenous culture and ecological knowledge. Overall, the VR360 system provided an accessible and effective learning experience, with participants reporting high levels of satisfaction. Notably, Indigenous students perceived the system as facilitating easier and more confident knowledge acquisition.

Future Research Directions

The experimental results indicate that both groups of students made significant improvements in learning about Tao culture and the natural environment of Orchid Island. However, the absence of a control group limits causal inference, as observed changes may be influenced by prior experience, or contextual factors. Future research should employ randomized or controlled experimental designs to better isolate intervention effects and strengthen causal conclusions regarding the impact of VR360-based learning.

Both ethnic groups demonstrated high levels of learning motivation and technology acceptance toward the VR360 system; however, they also experienced a moderate cognitive load during its usage. Future research could focus on optimizing the user interface and strengthening instructional support features to reduce cognitive load and further improve learning experience. Feedback from the Technology Acceptance Model (TAM) questionnaire suggests that although Indigenous students generally showed higher satisfaction with the VR360 system, there remains room for improvement in hardware accessibility, internet connectivity, and digital literacy. These factors may influence learning outcomes, and future studies should explore strategies to narrow the digital divide and enhance the system's adaptability for learners from diverse cultural backgrounds.

Future research could adopt longitudinal and cross-disciplinary designs to examine the long-term effects of VR-based instruction on knowledge retention and sustained motivation. Expanding the participant pool to include students from other Indigenous communities would help validate the system's cultural adaptability and inclusiveness. Besides, integrating Augmented Reality (AR) or Mixed Reality (MR) technologies could create blended learning environments that connect virtual and real-world experiences, offering deeper insights into how immersive tools support cultural learning and ecological understanding across various contexts.

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Taiwan is home to a wide range of Indigenous groups, each with distinct cultural traditions and knowledge systems. Future studies could incorporate the cultures of other Indigenous communities into the VR360 system and conduct cross-cultural analyses to broaden its application in protecting cultural heritage and environmental education. The use of VR360 technology could also be extended to diverse learning scenarios, such as virtual laboratories or historical site explorations, enabling students to acquire interdisciplinary knowledge alongside cultural understanding. Given its cross-regional potential, future research should explore international and cross-cultural comparisons to examine how learners from different countries engage with such systems and to assess their relevance for diverse linguistic and cultural groups. International collaboration represents another promising direction, as partnerships with global academic institutions to develop multilingual learning resources could substantially expand the system's educational impact worldwide.

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Declaration of Interest

The authors declare no competing interest.

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